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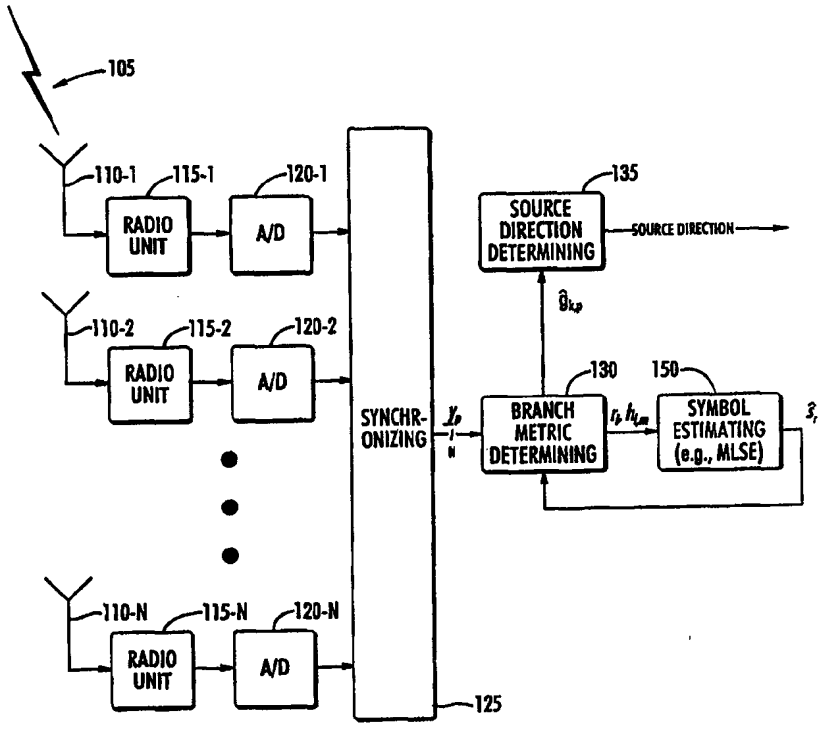
(54) Title: APPARATUS AND METHODS FOR DETERMINING SIGNAL DIRECTION FROM AN ESTIMATED SIGNAL MEDIUM RESPONSE FOR A RAY COMPONENT OF A RADIO SIGNAL

(57) Abstract

A direction for a desired radio signal arriving at a receiving station is determined from a plurality of estimated signal medium response coefficients for a ray of the desired radio signal. According to an aspect of the present invention, the estimated signal medium response coefficients for the ray are generated according to an interference rejection combining (IRC) process. According to another aspect, a direction of arrival for a ray of the desired signal is determined and used to compute a power spectral density for the ray for a plurality of directions. A direction of arrival for the ray is then determined by determining a direction for which the power spectral density has a maximum value. In addition to desired signal direction, direction of arrival for an interfering signal can be determined using an impairment autocorrelation matrix that is also generated as part of the IRC process.



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APPARATUS AND METHODS FOR DETERMINING SIGNAL DIRECTION FROM AN ESTIMATED SIGNAL MEDIUM RESPONSE FOR A RAY COMPONENT OF A RADIO SIGNAL

Field of the Invention

The present invention relates to communications apparatus and methods, more particularly, to apparatus and methods for determining a direction of a radio signal.

Background of the Invention

Wireless communications systems such as cellular radiotelephone systems typically are subject to performance-degrading environmental effects such as multi-path fading and interference. Fading effects include flat fading, arising from the interaction of a transmitted signal (the main ray) with reflected versions of the transmitted signal that arrive concurrently at a receiver. Time dispersion, another type of fading, arises from interaction of the main ray with time-delayed reflections of the main ray. Interference effects may be caused by interaction of non-orthogonal signals generated in the signal medium by sources other than the source of the desired transmitted signal. Well-known techniques for reducing the effects of flat fading include diversity combining of signals from spatially separated antennas. Equalization techniques such as maximum likelihood sequence estimation (MLSE) may be used to compensate for time dispersion. Interference may be reduced by using antenna beam steering to reduce reception of undesired signals.

United States Patent Application Serial No. 08/284,775, filed August 2, 1994, assigned to the assignee of the present invention and incorporated herein by reference, has proposed an interference rejection combining (IRC) technique which compensates for flat fading, time dispersion and interference. An impairment autocorrelation matrix is computed and used to compute branch metrics for a sequence estimation process which are corrected for the presence of interfering signals, i.e., impairments, using the autocorrelation properties of the interfering signals. According to United States Patent Application Serial No. 08/655,930, filed May 31, 1996, assigned to the

assignee of the present application and incorporated herein by reference in its entirety, IRC may be used to determine a covariance matrix of a desired signal, and downlink beamsteering techniques may be employed based on the determined covariance to improve communications between a mobile unit and a base station

Unfortunately, however, estimates of direction of arrival of a desired signal produced using the approach described in the aforementioned United States Patent Application Serial No. 08/655,930 can be inaccurate due to noise introduced in determining the covariance matrix of the desired signal. The noise susceptibility may in turn require increased sampling to achieve a desired accuracy for the estimate of the direction of arrival. Accordingly, there is a need for improved techniques of direction estimation that are less susceptible to noise and can provide more accurate results without requiring undue sampling.

Summary of the Invention

In light of the foregoing, it is an object of the present invention to provide apparatus and methods for determining a direction for a desired signal that are resistant to fading and interference effects.

It is another object of the present invention to provide apparatus and methods for determining a direction for a desired signal that can provide greater accuracy than conventional techniques.

It is yet another object of the present invention to provide apparatus and methods for determining direction of an interfering signal.

These and other objects, features and advantages are provided according to the present invention by apparatus and methods in which a direction for a desired radio signal arriving at a receiving station is determined from a plurality of estimated signal medium response coefficients for a ray of the desired radio signal. According to an aspect of the present invention, the estimated signal medium response coefficients for the ray are generated according to an interference rejection combining (IRC) process, an equalization process that compensates for interference. According to another aspect, a direction of arrival for a ray of the desired signal is determined and used to compute a power spectral density for the ray for a plurality of directions. A direction of arrival for the ray is then determined by determining a direction for which the power spectral density has a maximum value. By determining desired signal direction

utilizing coefficients for a ray which are normally generated as part of an IRC process, a technique for determining signal direction is provided which is potentially more efficient than conventional techniques. In addition to desired signal direction, direction of arrival for an interfering signal can be efficiently determined using an impairment autocorrelation matrix that is also generated as part of the IRC process.

In particular, according to the present invention, a direction for a desired radio signal generated in a communications medium is determined. A plurality of radio signals is received from the communications medium, e.g., at a like plurality of antennas. A plurality of estimated signal medium response coefficients for a ray of the desired radio signal are generated from the plurality of received radio signals. A direction for the desired radio signal is determined from the plurality of estimated signal medium response coefficients for the ray of the desired radio signal. A direction for the desired radio signal may be determined by determining a direction of arrival for the ray from the corresponding plurality of estimated signal medium response coefficients for the ray, and then determining a direction for the desired radio signal from the determined direction of arrival for the ray.

According to an aspect of the present invention, the plurality of estimated signal medium response coefficients for the ray may be generated by generating a first plurality of estimated signal medium response coefficients. An impairment autocorrelation matrix is then generated from the plurality of received signals and the first plurality of estimated signal medium response coefficients. A branch metric is generated from the generated impairment autocorrelation matrix and the first plurality of estimated signal medium response coefficients, and a symbol estimate is generated from the generated branch metric. A second plurality of estimated signal medium response coefficients may then be generated from the plurality of received signals and the generated symbol estimate.

According to another aspect of the present invention, the plurality of estimated signal medium response coefficients may be generated by generating a series of pluralities of estimated signal medium response coefficients over a time interval, processing the series of pluralities of estimated signal medium response coefficients with a tracking filter to produce a plurality of predicted signal medium response coefficients, and determining a determining a direction for the desired radio signal from the plurality of predicted signal medium response coefficients for the ray of the

desired radio signal. The desired radio signal may be formatted according to a slotted communications protocol defined according to a plurality of time slots, and the series of pluralities of estimated signal medium response coefficients may be generated over at least one of the plurality of time slots.

According to another tracking aspect, a plurality of impairment autocorrelation matrices may be estimated over a time interval, e.g., over a time slot or a plurality of time slots in a slotted communications system. The generated plurality of impairment autocorrelation matrices may then be processed with a tracking filter to produce a predicted impairment autocorrelation matrix. A branch metric may then be generated from the predicted impairment autocorrelation matrix, and used to generate an improved direction estimate.

According to yet another method aspect of the present invention, a direction of arrival for the ray is determined by determining an autocorrelation value for the ray of the desired radio signal. A plurality of power spectral density values may be then be determined for the ray at a like plurality of directions using the determined autocorrelation value. A direction of the plurality of directions having a maximum associated determined power spectral density value is then identified to thereby determine a direction of arrival for the ray. According to another tracking aspect, a plurality of directions of arrival for the ray may be determined over a time interval such as a time slot or plurality of time slots. The determined plurality of directions of arrival may be processed with a tracking filter to produce a predicted direction of arrival for the ray.

In other method aspects, a direction for an interfering radio signal is determined from the generated impairment autocorrelation matrix. A plurality of power spectral density values may be determined for the interfering radio signal at a like plurality of directions using the generated impairment autocorrelation matrix. A direction of the plurality of directions having a maximum associated determined power spectral density value may then be identified to thereby determine a direction for the interfering radio signal. The determined direction of arrival may be tracked over a time interval, such as a time slot or series of time slots.

An apparatus for receiving a desired radio signal generated in a communications medium includes means, responsive to the communications medium, for receiving a plurality of radio signals from the communications medium. Means

are responsive to the means for receiving for generating a plurality of estimated signal medium response coefficients for a ray of the desired radio signal from the plurality of received radio signals. Means are also provided, responsive to the means for generating, for determining a direction for the desired radio signal from the plurality of estimated signal medium response coefficients for the ray of the desired radio signal. The means for determining a direction for the desired radio signal may comprise means for determining a direction of arrival for the ray from the corresponding plurality of estimated signal medium response coefficients for the ray, as well as means for determining a direction for the desired radio signal from the determined direction of arrival for the ray.

The means for generating a plurality of estimated signal medium response coefficients may include means for generating a first plurality of estimated signal medium response coefficients. Means are responsive to the means for generating a first plurality of estimated signal medium response coefficients, for generating an impairment autocorrelation matrix from the plurality of received signals and the first plurality of estimated signal medium response coefficients. Additional means are provided, responsive to the means for generating an impairment autocorrelation matrix, for generating a branch metric from the generated impairment autocorrelation matrix and the first plurality of estimated signal medium response coefficients. Means are also provided, responsive to the means for generating a branch metric, for generating a symbol estimate from the generated branch metric. Means for generating a second plurality of estimated signal medium response coefficients from the plurality of received signals and the generated symbol estimate are provided. The apparatus may further include means for determining a direction for an interfering radio signal of the plurality of radio signals from the generated impairment autocorrelation matrix.

Brief Description of the Drawings

Some of the objects and advantages of the present invention having been stated, others will be more fully understood from the detailed description that follows and by reference to the accompanying drawings in which:

FIG. 1 is a schematic illustration of an apparatus for determining a direction for a desired signal according to an embodiment of the present invention;

FIG. 2 is a schematic illustration of an apparatus for determining signal medium response coefficients and branch metrics using interference rejection combining according to an embodiment of the present invention;

FIG. 3 is a schematic illustration of an apparatus for determining a direction for a desired signal according to an embodiment of the present invention;

FIG. 4 is a schematic illustration of an apparatus for determining a direction for an interfering signal according to an aspect of the present invention; and

FIG. 5 is a flowchart illustration of operations for determining a direction for a desired signal according to an aspect of the present invention.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. Those skilled in the art will appreciate that the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

Interference Rejection Combining

A transmitted symbol sequence may be represented as $s=\{s_{-L},\ldots,s_L\}$. A signal $\underline{r}(t)$ presented at N_a antennas may be take the vector form

$$\underline{r}(t) = \underline{s}_0(t;\ s_0) + \underline{w}(t), \tag{1}$$

where a desired signal $\underline{S}_0(t;s_0)$ may be represented as

$$\underline{s}_0(t;s_o) = \sum_{l=-L}^{L} s_{0,l}\,\underline{h}(t,lT), \tag{2}$$

$\underline{w}(t)$ is an impairment process, $h(t,lT)$ is a composite signal medium, i.e., channel, response for the desired signal and T is the symbol interval. It may be assumed that

the impairment process contains both N_i undesired, e.g., interfering, signals and a zero-mean, white noise process $\underline{n}(t)$ such that

$$\underline{w}(t) = \sum_{i=1}^{N_i} \underline{s}_i(t;s_i) + \underline{n}(t), \tag{3}$$

where the undesired signals $s_i(t;s_i)$ have a similar form to the desired signal of equation (2) and wherein

$$E\{\underline{n}(t)\underline{n}^H(s)\} = \frac{N_0}{2}\delta(t-s), \tag{4}$$

where N_0 is the noise power spectral density. A composite signal medium response for the desired signal may be resolved into two components: (1) a propagation signal medium response $\mathbf{g}(t, lT)$ and (2) a fixed transmit filter response $f(t, lT)$. The composite signal medium response $\underline{\mathbf{h}}(t,lT)$ may then be assumed to have the form

$$\begin{aligned} \underline{h}(t,lT) &= \sum_{k=-\infty}^{\infty} f(t-(k+lM)T_s)\underline{g}_k(t) \\ &\approx \sum_{k=-\infty}^{\infty} f(t-(k+lM)T_s)\underline{g}_{k,k+lM}, \end{aligned} \tag{5}$$

where t is time, T_s is the sample interval, M is the number of samples per symbol interval t, and g_k are the channel tap coefficients for the channel response, the kth channel tap is assumed to be constant over the transmit pulse. Those skilled in the art will appreciate that the above relationship may be used when the sample interval T_s is a fraction of the symbol interval T, corresponding to M equal to an integer greater than one.

An equalizer may compute a log-likelihood metric $LL(\underline{s};\underline{r}(t))$ for a hypothesized symbol $\underline{s}$ given a received signal $\underline{r}(t)$ according to

$$\begin{aligned} LL(\underline{s};\underline{r}(t)) &= \sum_{l=-L}^{L} 2\,\mathrm{Re}\{s_l^* r_l\} - \sum_{l=-L}^{L}\sum_{m=-L}^{L} s_l^* h_{l,m} s_m \\ &= \sum_{l=-L}^{L}\left[2\,\mathrm{Re}\{s_l^* r_l\} - |s_l|^2 h_{l,l} - \sum_{n=1}^{l+L} s_l^* h_{l,l-n} s_{l-n}\right] \end{aligned} \tag{6}$$

where

$$r_l = \sum_{k=-\infty}^{\infty} \underline{g}_{k,k+lM}^{H} \underline{y}_{k+lM} \tag{7}$$

represents the overall channel matched response,

$$y_p = \int_{-\infty}^{\infty} f^*(t - pT_s)\underline{r}(t)dt \tag{8}$$

represents the filter matched response,

$$h_{l,m} = \sum_{k=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} \underline{g}_{k,k+lM}^{H} \underline{g}_{j,j+mM} \rho_{(k-j)-(l-m)M} \tag{9}$$

represents an interaction term for symbols s_l and s_m, and

$$\rho_{(k-j)-(l-m)M} = \int_{-\infty}^{\infty} f^*(t-(k+lM)T_s) f(t-(j+mM)T_s)dt \tag{10}$$

represents the pulse autocorrelation function.

For a symbol-spaced equalizer with Nyquist pulse shapes, equations (8) and (9) become

$$y_p = \int_{-\infty}^{\infty} f^*(t - pT)\underline{r}(t)dt \tag{11}$$

and

$$h_{l,m} = \sum_{k=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} \underline{g}_{k,k+l}^{H} \underline{g}_{k+(l-m),k+l}, \tag{12}$$

respectively.

In performing interference rejection combining, the impairment spatial autocorrelation matrix is estimated and inserted into the metric equations in the following manner:

$$r_l = \sum_{k=-\infty}^{\infty} \underline{g}_{k,k+lM}^H \int_{\infty}^{\infty} \mathbf{R}^{-1}(\tau,(k+lM)T_s) y((k+lM)T_s-\tau)d\tau$$
$$\approx \sum_{k=-\infty}^{\infty} \underline{g}_{k,k+lM}^H \sum_{i=-\infty}^{\infty} \mathbf{R}_{i,k+lM}^{-1} \underline{y}_{k+lM-i}, \quad (13)$$

and

$$h_{l,m} = \sum_{k=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} \underline{g}_{k,k+lM}^H \mathbf{Q}_{k-j+(l-m)M,k+lM} g_{j,j+mM}, \quad (14)$$

where

$$\mathbf{Q}_{k-j+(l-m)M,k+lM} = \int_{-\infty}^{\infty} \mathbf{R}^{-1}(\tau,(k+lM)T_s)\rho((k+lM)T_s-(j+mM)T_s-\tau)d\tau,$$
$$\approx \sum_{i=-\infty}^{\infty} \mathbf{R}_{i,k+lM}^{-1} \rho_{(k-j-i)+(l-m)M}. \quad (15)$$

In other words, the impairment autocorrelation matrix **R** is used to generate branch metrics which are compensated for the presence of interfering signals. The above approach is discussed in the aforementioned United States Patent Application Serial Number 08/284,775.

Direction Estimation Using Phased Arrays

Consider a received signal taking the form

$$\underline{x}(t) = \underline{a}(\Phi)s(t) + \underline{n}(t), \quad (16)$$

where $\underline{a}(\Phi)$ is the directional component of the signal presented at the array elements, s(t) is the transmitted signal and $\underline{n}(t)$ is a zero-mean, white noise component. Let $\underline{y}(t)=\mathbf{A}^H\underline{x}(t)$ be the beamformed signal where **A** is the beamforming matrix. The spatial power spectrum of the signal $\underline{x}(t)$ may be estimated by computing

$$P_x(\Phi) = \frac{\underline{a}^H(\Phi)\mathbf{R}_{xx}\underline{a}(\Phi)}{\left|\underline{a}(\Phi)\right|^2} \tag{17}$$

where the autocorrelation matrix $\mathbf{R}_{xx}$ is estimated by

$$\mathbf{R}_{xx}(\Phi) = \frac{1}{N}\sum_{n=1}^{N}\underline{x}(t-nT_s)\underline{x}^H(t-nT_s). \tag{18}$$

The spatial power spectrum $P_y(\Phi)$ may similarly be computed as

$$P_y(\Phi) = \frac{\left[\mathbf{A}^H\underline{a}(\Phi)\right]^H\mathbf{R}_{yy}\left[\mathbf{A}^H\underline{a}(\Phi)\right]}{\left|\mathbf{A}^H\underline{a}(\Phi)\right|^2} \tag{19}$$

where the autocorrelation matrix $\mathbf{R}_{yy}$ is estimated by

$$\begin{aligned}\mathbf{R}_{yy}(\Phi) &= \frac{1}{N}\sum_{n=1}^{N}\underline{y}(t-nT_s)\underline{y}^H(t-nT_s)\\ &= \mathbf{A}^H\mathbf{R}_{xx}\mathbf{A}.\end{aligned} \tag{20}$$

The estimated direction is may then be computed by finding the value of the direction variable Φ that maximizes either equation (17) or (19).

In the aforementioned United States Patent Application Serial Number 08/655,930, a direction of arrival for a desired signal is estimated by maximizing power spectral density as shown above using a interferer-compensated overall signal autocorrelation $\mathbf{R}_{xx}$ computed as $\mathbf{R}_{xx} = \mathbf{R}_{rr} - \mathbf{R}_{ii}$, where $\mathbf{R}_{rr}$ represents a running average of a received signal and $\mathbf{R}_{ii}$ is an overall impairment autocorrelation matrix. Although this approach can provide an accurate estimate of direction of arrival, it may introduce noise which can reduce accuracy and/or which may require increased sampling to obtain a desired level of accuracy.

The present invention arises from the realization that an accurate estimate of a direction for a desired signal may be obtained directly from estimated signal medium response coefficients (channel taps) for a ray of the desired signal, i.e., for a

component of the desired signal at one or more delays, instead of computing an overall autocorrelation for the desired signal and using it to determine a direction of arrival for the desired signal. According to the present invention, the estimated signal medium response coefficients $g_{k,k+lM}$ for a *k*th ray of the desired signal may be assumed to be a function of some direction parameter $\underline{\Phi}_k$; for example, $\underline{\Phi}_k=[\Phi_{k,az},\Phi_{k,el}]$ may describe the azimuth and elevation angles, respectively, of the medium response for the *k*th ray of the desired signal, where either $\Phi_{k,az}$ or $\Phi_{k,el}$ may itself be known or assumed known.

According to an aspect of the present invention, an autocorrelation for the *k*th ray may be computed as

$$\mathbf{R}_{gkgk}(\Phi_k)=\frac{1}{N}\sum_{n=1}^{N}\underline{g}_{k,k+lM}\,\underline{g}^{H}_{k,k+lM}, \tag{21}$$

allowing a spectral power density for the *k*th ray to be computed as

$$P_{gk}(\Phi_k)=\frac{\left[A^H\,\underline{a}^H(\underline{\Phi}_k)\right]\mathbf{R}_{gkgk}\left[\mathbf{A}^H\,\underline{a}(\underline{\Phi}_k)\right]}{\left|\mathbf{A}^H\,\underline{a}(\underline{\Phi}_k)\right|^2} \tag{22}$$

The estimated direction for the *k*th ray can be estimated by finding the value of $\underline{\Phi}_k$ that maximizes $P_{gk}(\underline{\Phi}_k)$. The $g_{k,k+lM}$ represent a signal medium response for a *k*th ray, and in order to compute estimates of these components, the filtered data y_{k+lM} may be used. In addition to this power spectral density maximization technique, other techniques may be used to determined direction for a ray based on the $g_{k,k+lM}$, as will be discussed in greater detail below.

Estimation of the direction for desired signal may computed from the determined direction of arrival of a ray of the desired signal in a number of ways. A particular ray might be selected for DOA computation because it may provide the greatest accuracy, for example. In other embodiments, a weighted combination of direction of arrival estimates for a plurality of rays of the desired signal may be computed to provide an accurate estimate of the direction of the source.

The direction of arrival information may be used for beamsteering and other applications. In addition, estimates of the directional components of an undesired signal may be generated using $\mathbf{R}_{I,k+IM}$ in a spatial power spectral density equation, and determining the direction of arrival for the undesired signal which maximizes power spectral density, as described above. This information may be advantageously used for antenna pattern nulling and other purposes, as described in greater detail below.

Estimating Direction from Estimated Signal Medium Response Coefficients of a Component Ray

FIG. 1 illustrates the use of interference rejection combining (IRC) to produce estimated signal medium response coefficients $\hat{g}_{k,p}$ according to an embodiment of the present invention. N antennas **110-1, . . . , 110-N** receive a plurality of radio signals from a composite signal **105** arriving at a receiving station **100**. The plurality of received radio signals are passed to N radio units **115-1, · · · , 115-N**. These signals are output from the radio units **115-1, · · ·, 115-N** and digitized by analog-to-digital (A/D) converters **120-1, · · · , 120-N**. A synchronizer **125** performs synchronization on these signals, resulting in a N-dimensional vector output signal $\underline{y}_p$. Those skilled in the art will appreciate that synchronization may be performed jointly using all digitized signals to come up with one common sample timing, or may be performed individually for each digitized signal.

The signal $\underline{y}_p$ is passed to a branch metric determining means **130**, which computes branch metrics $\mathbf{r}_l$ and $\mathbf{h}_{l,m}$ for use in the symbol estimating means **150**. The branch metric determining means **130** also produces estimated signal medium response coefficients $\hat{g}_{k,p}$ based on the received signal data $\underline{y}_p$, as well as an impairment autocorrelation matrix $\underline{\mathbf{R}}_{i,p}$ which is also estimated from the received data $\underline{y}_p$. The symbol estimating means **150** produces an estimated symbol $\hat{s}_r$, performing symbol hypothesis and detection using, for example, a Viterbi algorithm employed as part of a maximum likelihood sequence estimation (MLSE) process. A direction determining means **135** determines a direction for the desired signal from the

estimated signal medium response coefficients $\hat{g}_{k,p}$ for the *k*th ray of the desired signal.

Those skilled in the art will appreciate that the radio units **115-1, · · · , 115-N**, A/D converters **120-1, · · · , 120-N**, the synchronizer **125**, the branch metric determining means **130**, the symbol estimating means **150**, and the direction determining means **135** may include a variety of commonly-used communications components such as filters, demodulators, digital signal processors and the like, the operation of which is well-know to those of skill in the art and need not be discussed in detail herein. In general, it will be appreciated that the functions of these components may be implemented using special-purpose hardware, software or firmware running on general or special purpose data processors, and combinations thereof.

FIG. 2 illustrates an embodiment of the branch metric determining means **130** of FIG. 1 in detail. A memory **220** stores estimated signal medium response coefficients $\hat{\underline{g}}_{0,p},\cdots,\hat{\underline{g}}_{N-1,p}$ generated by signal medium response estimating means **210**. A delay **215** is provided between the signal medium response estimating means **210** and the memory **220**. The signal medium response estimating means **210** generates estimated signal medium response coefficients $\hat{\underline{g}}_{0,p},\cdots,\hat{\underline{g}}_{N-1,p}$ given previously generated estimated signal medium response coefficients $\hat{\underline{g}}_{0,p-1},\cdots,\hat{\underline{g}}_{N-1,p-1}$ received from the memory **220**, received data $\underline{y}_p$ and a symbol hypothesis $\hat{s}_l$, which may be a symbol estimate obtained using an MLSE or other symbol estimating process such as one performed by the symbol estimating means **150** depicted in FIG. 1. To provide improved accuracy, a known training sequence, i.e., a synchronization sequence, may be employed to assist in estimation of the signal medium response in the signal medium response estimating means **210**. For example, the training sequence may be used as the source of an initial symbol hypothesis $\hat{s}_l$ for determining the estimated signal medium response coefficients $\hat{\underline{g}}_{0,p},\cdots,\hat{\underline{g}}_{N-1,p}$.

Signal medium response predicting means **240** uses the estimated signal medium response coefficients $\hat{\underline{g}}_{0,p},\cdots,\hat{\underline{g}}_{N-1,p}$ to produce estimated future signal response medium coefficients $\hat{\underline{g}}_{0,r},\cdots,\hat{\underline{g}}_{N-1,r}$, which are in turn used to compute the

branch metrics $h_{l,m}$ and r_l. Impairment autocorrelation estimating means **225** computes impairment autocorrelation values $\mathbf{R}_{i,p}$ (an N x N matrix) from an error signal $\underline{e}_p$ representing a difference between the received data $\underline{y}_p$ and the symbol hypothesis $\hat{s}_l$. The impairment autocorrelation matrix $\mathbf{R}_{i,p}$ may be computed for sample time p and different delay indices i; setting $i \in \{0\}$ gives conventional interference rejection combining. A second delay **230** produces delayed impairment autocorrelation values $\mathbf{R}_{i,p-1}$, for use in estimating the impairment autocorrelation values $\mathbf{R}_{i,p}$.

First branch metric computing means **245** computes a first branch metric $h_{l,m}$, e.g., using equations (14) and (15), augmented by pulse autocorrelation values $\rho_{k-j+(l-m)M}$ provided by a pulse autocorrelation determining means **255**, e.g., a look-up table of pulse autocorrelation values. A second branch metric computing determining means **250** computes a second metric r_l as in equation (13). It may be assumed that the summations in equation (13) are finite, i.e.,

$$r_l = \sum_{k=0}^{N-1} \underline{g}_{k,k+lM}^{H} \sum_{i=0}^{I-1} \mathbf{R}_{i,k+lM}^{-1} \underline{y}_{k+lM-i}$$

and that all terms are available. As illustrated in FIG. 1, the first and second metrics $h_{l,m}$ and r_l may be used by the symbol estimating means **150** to produce the estimated symbol values $\hat{s}_r$. Those skilled in the art will appreciate that various apparatus may be used to produce the symbol values $\hat{s}_r$, such as MLSE sequence estimators, decision decoders and the like.

The estimated signal medium response coefficients $\underline{\hat{g}}_{0,p}, \cdots, \underline{\hat{g}}_{N-1,p}$ for a desired signal and the estimated impairment autocorrelation values $\mathbf{R}_{i,p}$ may be used to determine a direction for a desired signal. FIG. 3 illustrates an exemplary structure in which a ray autocorrelation determining means **310** determines an autocorrelation $\mathbf{R}_{gk,p}$ for the *k*th ray of the desired signal across antennas, e.g., as described in equation (21). This value is used by a power spectral density determining means **320** to determine spatial power spectral density values $P_{gk}(\Phi_k)$ for the *k*th ray as described in equation (22). Note that this may be performed for Φ_k belonging to a set of

hypothesized directions $\{\Phi_k\}$. A ray direction determining means **330** determines a value of Φ_k that maximizes $Pg_k(\Phi_k)$, producing an estimated direction of arrival $\hat{\Phi}_{g_k}$ for the *k*th ray.

Those skilled in the art will appreciate that $P_{gk}(\Phi_k)$ can be smoothed or averaged over time to give better estimates. $Pg_k(\Phi_k)$ can also be averaged over multiple antenna arrays to obtain spatial averaging. The estimated direction of a arrival $\hat{\Phi}_{g_k}$ for a *k*th ray, e.g., a main ray, may be used alone to estimate the direction of the desired signal, or a weighted combination of estimated directions of a arrival for a plurality of rays may be used to determine a direction for the desired signal.

A direction of arrival for an interfering signal can also be obtained using the interference rejection combining process. Because the interference rejection combining process illustrated in FIG. 2 can provide impairment autocorrelation values $\mathbf{R}_{i,p}$ directly, the direction of arrival for the interfering signal may be directly determined by determining the interfering signal's power spectral density $P_i(\Phi_k)$ for a plurality of directions Φ_k in a power spectral density determining means **410**, and determining the value $\hat{\Phi}_i$ that maximizes the interfering signal's power spectral density $P_i(\Phi_k)$ in an interfering signal direction determining means **420**.

Additional operations may also be performed to generate improve direction estimates. In a slotted time division multiple access (TDMA) system, for example, the direction estimates $\hat{\Phi}_{g_k}$ and/or $\hat{\Phi}_i$ may be tracked over one or more slots using a tracking filter **350**, **420** to yield predicted directions $\hat{\Phi}_{g_k}'$, $\hat{\Phi}_i'$. Similarly, the estimated signal medium response coefficients $\underline{\hat{g}}_{0,p},\cdots,\underline{\hat{g}}_{N-1,p}$ and the impairment autocorrelation values $\mathbf{R}_{i,p}$ may be tracked within a slot or over a plurality of slots to produce improved direction estimates.

Those skilled in the art will appreciate that the apparatus illustrated in FIGs. 2-4 may include a variety of commonly-used communications components. For example, the apparatus of FIG. 2 may be implemented using one or more digital signal processor (DSP) chips and/or application specific integrated circuits (ASICs). In general, it will be appreciated that the apparatus of FIGs. 2-4 may be implemented using special-purpose hardware, software or firmware running on general or special purpose data processors, and combinations thereof.

It will be appreciated that techniques for determining directions for desired and interfering signals other than the aforementioned spectral power density maximization approach may be used with the present invention. For example, a technique could be utilized which determine direction using signal strength estimates computed from the g_k , similar to the technique described in United States Patent Application Serial Number 08/597,073. Other approaches, such ones based on the MUSIC techniques described in "A Signal Subspace Approach to Multiple Emitter Location and Spectral Estimation", by Schmidt (Stanford University Ph.D. dissertation, 1981), or the ESPRIT techniques described in "ESPRIT, Estimation of Signal Parameters via Rotational Invariance Techniques", by Roy (Stanford University Ph.D. dissertation, 1987), could be used as well.

The directional information for desired and interfering signals may be used for a number of different purposes. For example, the estimated directions $\hat{\Phi}_{g_k}$ and $\hat{\Phi}_i$ may be used to steer maximum gain portions of an antenna pattern to advantageously receive a desired signal, in a manner similar to the beamsteering operations described in the aforementioned U.S. Patent Application Serial No. 08/655,930. Estimates of interfering signal directions may be used, for example, for nulling a receive antenna pattern to reduce interference, as well as for such features as predicting mobile unit handoffs and the like.

FIG. 5 is a flowchart illustration of operations for determining a direction for a desired signal arriving at a receiving station (Block **500**). A plurality of radio signals are received at a plurality of antennas (Block **510**). A plurality of estimated signal medium response coefficients for a ray of the desired radio signal are generated from the plurality of received signals (Block **520**), e.g., using in interference rejection combining technique as described with respect to FIG. 2. A direction for the desired signal is determined from the plurality of estimated signal medium response coefficients for the ray of the desired signal (Block **530**), for example, by computing an autocorrelation for the ray and determining a direction that maximizes a power spectral density function of the autocorrelation.

In the drawings and specification, there have been disclosed typical embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

THAT WHICH IS CLAIMED IS:

1. A method of determining a direction for a desired radio signal generated in a communications medium, the method comprising the steps of:

receiving a plurality of radio signals from the communications medium;

generating a plurality of estimated signal medium response coefficients for a ray of the desired radio signal from the plurality of received radio signals; and

determining a direction for the desired radio signal from the plurality of estimated signal medium response coefficients for the ray of the desired radio signal.

2. A method according to Claim 1, wherein said step of receiving comprises the step of receiving the plurality of radio signals at a like plurality of antennas.

3. A method according to Claim 2:

wherein said step of determining a direction for the desired radio signal comprises the step of determining a direction of arrival for the ray from the corresponding plurality of estimated signal medium response coefficients for the ray; and

wherein said step of determining a direction for the desired radio signal comprises the step of determining a direction for the desired radio signal from the determined direction of arrival for the ray.

4. A method according to Claim 2:

wherein said step of generating a plurality of estimated signal medium response coefficients comprises the steps of:

generating a series of pluralities of estimated signal medium response coefficients over a time interval; and

processing the series of pluralities of estimated signal medium response coefficients with a tracking filter to produce a plurality of predicted signal medium response coefficients; and

wherein said step of determining a direction for the desired radio signal comprises the step of determining a direction for the desired radio signal from the

plurality of predicted signal medium response coefficients for the ray of the desired radio signal.

5. A method according to Claim 4, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, wherein said step of generating a series of pluralities of estimated signal medium response coefficients over a time interval comprises the step of generating a series of pluralities of estimated signal medium response coefficients over at least one of said plurality of time slots.

6. A method according to Claim 2, wherein the desired radio signal represents a sequence including a predetermined training sequence, and wherein said step of generating a plurality of estimated signal medium response coefficients comprises the step of generating a plurality of estimated signal medium response coefficients from the plurality of received radio signals based on the predetermined training sequence.

7. A method according to Claim 2, wherein said step of generating a plurality of estimated signal medium response coefficients for the ray comprises the steps of:

generating a first plurality of estimated signal medium response coefficients;

generating an impairment autocorrelation matrix from the plurality of received signals and a symbol estimate;

generating a branch metric from the generated impairment autocorrelation matrix and the first plurality of estimated signal medium response coefficients;

generating a new symbol estimate from the generated branch metric; and

generating a second plurality of estimated signal medium response coefficients from the plurality of received signals and the generated new symbol estimate.

8. A method according to Claim 7:

wherein said step of generating an impairment autocorrelation matrix comprises the steps of:

generating a plurality of impairment autocorrelation matrices over a time interval; and

processing the generated plurality of impairment autocorrelation matrices with a tracking filter to produce a predicted impairment autocorrelation matrix; and

wherein said step of generating a branch metric comprises the step of generating the branch metric from the predicted impairment autocorrelation matrix.

9. A method according to Claim 8, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said step of generating a plurality of impairment autocorrelation matrices over a time interval comprises the step of generating a plurality of impairment autocorrelation matrices over at least one time slot of said plurality of time slots.

10. A method according to Claim 7, wherein said step of generating a symbol estimate comprises the step of generating a symbol estimate from the generated branch metric according to a maximum likelihood sequence estimation (MLSE) process.

11. A method according to Claim 3, wherein said step of determining a direction of arrival for the ray comprises the steps of:

determining an autocorrelation value for the ray of the desired radio signal;

determining a plurality of power spectral density values for the ray at a like plurality of directions using the determined autocorrelation value; and

identifying a direction of the plurality of directions having a maximum associated determined power spectral density value to thereby determine a direction of arrival for the ray.

12. A method according to Claim 3:

wherein said step of determining a direction of arrival for the ray comprises the steps of:

determining a plurality of directions of arrival for the ray over a time interval; and

processing the determined plurality of directions of arrival with a tracking filter to produce a predicted direction of arrival for the ray; and

wherein said step of determining a direction for the desired radio signal from the determined direction of arrival for the ray comprises the step of determining a direction for the desired radio signal from the predicted direction of arrival for the ray.

13. A method according to Claim 12, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said step of determining a plurality of directions of arrival for the ray over a time interval comprises the step of determining a plurality of directions of arrival for the ray over at least one of said plurality of time slots.

14. A method according to Claim 7, further comprising the step of determining a direction for an interfering radio signal of the plurality of radio signals from the generated impairment autocorrelation matrix.

15. A method according to Claim 8, further comprising the step of determining a direction for an interfering radio signal of the plurality of radio signals from the predicted impairment autocorrelation matrix.

16. A method according to Claim 9, further comprising the step of determining a direction for an interfering radio signal of the plurality of radio signals from the predicted impairment autocorrelation matrix.

17. A method according to Claim 14, wherein said step of determining a direction for an interfering radio signal comprises the steps of:

determining a plurality of power spectral density values for the interfering radio signal at a like plurality of directions using the generated impairment autocorrelation matrix; and

identifying a direction of the plurality of directions having a maximum associated determined power spectral density value to thereby determine a direction for the interfering radio signal.

18. A method according to Claim 17, wherein said step of determining a direction for the interfering radio signal comprises the steps of:

determining a plurality of directions of arrival for the interfering radio signal over a time interval; and

processing the determined plurality of directions of arrival with a tracking filter to produce a predicted direction of arrival for the interfering radio signal.

19. A method according to Claim 18, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said step of determining a plurality of directions of arrival for the interfering radio signal over a time interval comprises the step of determining a plurality of directions of arrival for the interfering radio signal over at least one of said time slots.

20. An apparatus for receiving a desired radio signal generated in a communications medium, the station comprising:

means, responsive to the communications medium, for receiving a plurality of radio signals from the communications medium;

means, responsive to said means for receiving, for generating a plurality of estimated signal medium response coefficients for a ray of the desired radio signal from the plurality of received radio signals; and

means, responsive to said means for generating, for determining a direction for the desired radio signal from the plurality of estimated signal medium response coefficients for the ray of the desired radio signal.

21. An apparatus according to Claim 20, wherein said means for receiving comprises a plurality of antennas, a respective one of which produces a respective one of the plurality of received signals.

22. An apparatus according to Claim 21:

wherein said means for determining a direction for the desired radio signal comprises means for determining a direction of arrival for the ray from the corresponding plurality of estimated signal medium response coefficients for the ray; and

wherein said means for determining a direction for the desired radio signal comprises means for determining a direction for the desired radio signal from the determined direction of arrival for the ray.

23. An apparatus according to Claim 21:

wherein said means for generating a plurality of estimated signal medium response coefficients comprises:

means for generating a series of pluralities of estimated signal medium response coefficients over a time interval; and

means for processing the series of pluralities of estimated signal medium response coefficients with a tracking filter to produce a plurality of predicted signal medium response coefficients; and

wherein said means for determining a direction for the desired radio signal comprises means for determining a determining a direction for the desired radio signal from the plurality of predicted signal medium response coefficients for the ray of the desired radio signal.

24. An apparatus according to Claim 23, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, wherein said means for generating a series of pluralities of estimated signal medium response coefficients over a time interval comprises means for generating a series of pluralities of estimated signal medium response coefficients over at least one of said plurality of time slots.

25. An apparatus according to Claim 22, wherein the desired radio signal represents a sequence including a predetermined training sequence, and wherein said means for generating a plurality of estimated signal medium response coefficients

comprises means for generating a plurality of estimated signal medium response coefficients from the plurality of received radio signals based on the predetermined training sequence.

26. An apparatus according to Claim 23, wherein said means for generating a plurality of estimated signal medium response coefficients for the ray comprises:

means for generating a first plurality of estimated signal medium response coefficients;

means, responsive to said means for generating a first plurality of estimated signal medium response coefficients, generating an impairment autocorrelation matrix from the plurality of received signals and a symbol estimate;

means, responsive to said means for generating an impairment autocorrelation matrix, for generating a branch metric from the generated impairment autocorrelation matrix and the first plurality of estimated signal medium response coefficients;

means, responsive to said means for generating a branch metric, for generating a new symbol estimate from the generated branch metric; and

means, responsive to said means for generating a symbol estimate, for generating a second plurality of estimated signal medium response coefficients from the plurality of received signals and the generated new symbol estimate.

27. An apparatus according to Claim 26:

wherein said means for generating an impairment autocorrelation matrix comprises:

means for generating a plurality of impairment autocorrelation matrices over a time interval; and

means, responsive to said means for generating a plurality of impairment autocorrelation matrices, for processing the generated plurality of impairment autocorrelation matrices with a tracking filter to produce a predicted impairment autocorrelation matrix; and

wherein said means for generating a branch metric comprises means for generating the branch metric from the predicted impairment autocorrelation matrix.

28. An apparatus according to Claim 27, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said means for generating a plurality of impairment autocorrelation matrices over a time interval comprises means for generating a plurality of impairment autocorrelation matrices over at least one time slot of said plurality of time slots.

29. An apparatus according to Claim 26, wherein said means for generating a symbol estimate comprises means for generating a symbol estimate from the generated branch metric according to a maximum likelihood sequence estimation (MLSE) process.

30. An apparatus according to Claim 22, wherein said means for determining a direction of arrival for the ray comprises:

means for determining an autocorrelation value for the ray of the desired radio signal;

means, responsive to said means for determining an autocorrelation value for the ray, for determining a plurality of power spectral density values for the ray at a like plurality of directions using the determined autocorrelation value; and

means, responsive to said means for determining a plurality of power spectral density values, for identifying a direction of the plurality of directions having a maximum associated determined power spectral density value to thereby determine a direction of arrival for the ray.

31. An apparatus according to Claim 22:

wherein said means for determining a direction of arrival for the ray comprises:

means for determining a plurality of directions of arrival for the ray over a time interval; and

means, responsive to said means for determining a plurality of directions of arrival, for processing the determined plurality of directions of

arrival with a tracking filter to produce a predicted direction of arrival for the ray; and

wherein said means for determining a direction for the desired radio signal from the determined direction of arrival for the ray comprises means for determining a direction for the desired radio signal from the predicted direction of arrival for the ray.

32. An apparatus according to Claim 31, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said means for determining a plurality of directions of arrival for the ray over a time interval comprises means for determining a plurality of directions of arrival for the ray over at least one of said plurality of time slots.

33. An apparatus according to Claim 27, further comprising means for determining a direction for an interfering radio signal of the plurality of radio signals from the generated impairment autocorrelation matrix.

34. An apparatus according to Claim 27, further comprising means for determining a direction for an interfering radio signal of the plurality of radio signals from the predicted impairment autocorrelation matrix.

35. An apparatus according to Claim 28, further comprising means for determining a direction for an interfering radio signal of the plurality of radio signals from the predicted impairment autocorrelation matrix.

36. An apparatus according to Claim 33, wherein said means for determining a direction for an interfering radio signal comprises:

means for determining a plurality of power spectral density values for the interfering radio signal at a like plurality of directions using the generated impairment autocorrelation matrix; and

means, responsive to said means for determining a plurality of power spectral density values, for identifying a direction of the plurality of directions having a

maximum associated determined power spectral density value to thereby determine a direction for the interfering radio signal.

37. An apparatus according to Claim 36, wherein said means for determining a direction for the interfering radio signal comprises:

means for determining a plurality of directions of arrival for the interfering radio signal over a time interval; and

means, responsive to said means for determining a plurality of directions of arrival, for processing the determined plurality of directions of arrival with a tracking filter to produce a predicted direction of arrival for the interfering radio signal.

38. An apparatus according to Claim 37, wherein the desired radio signal is formatted according to a slotted communications protocol defined according to a plurality of time slots, and wherein said means for determining a plurality of directions of arrival for the interfering radio signal over a time interval comprises means for determining a plurality of directions of arrival for the interfering radio signal over at least one of said time slots.

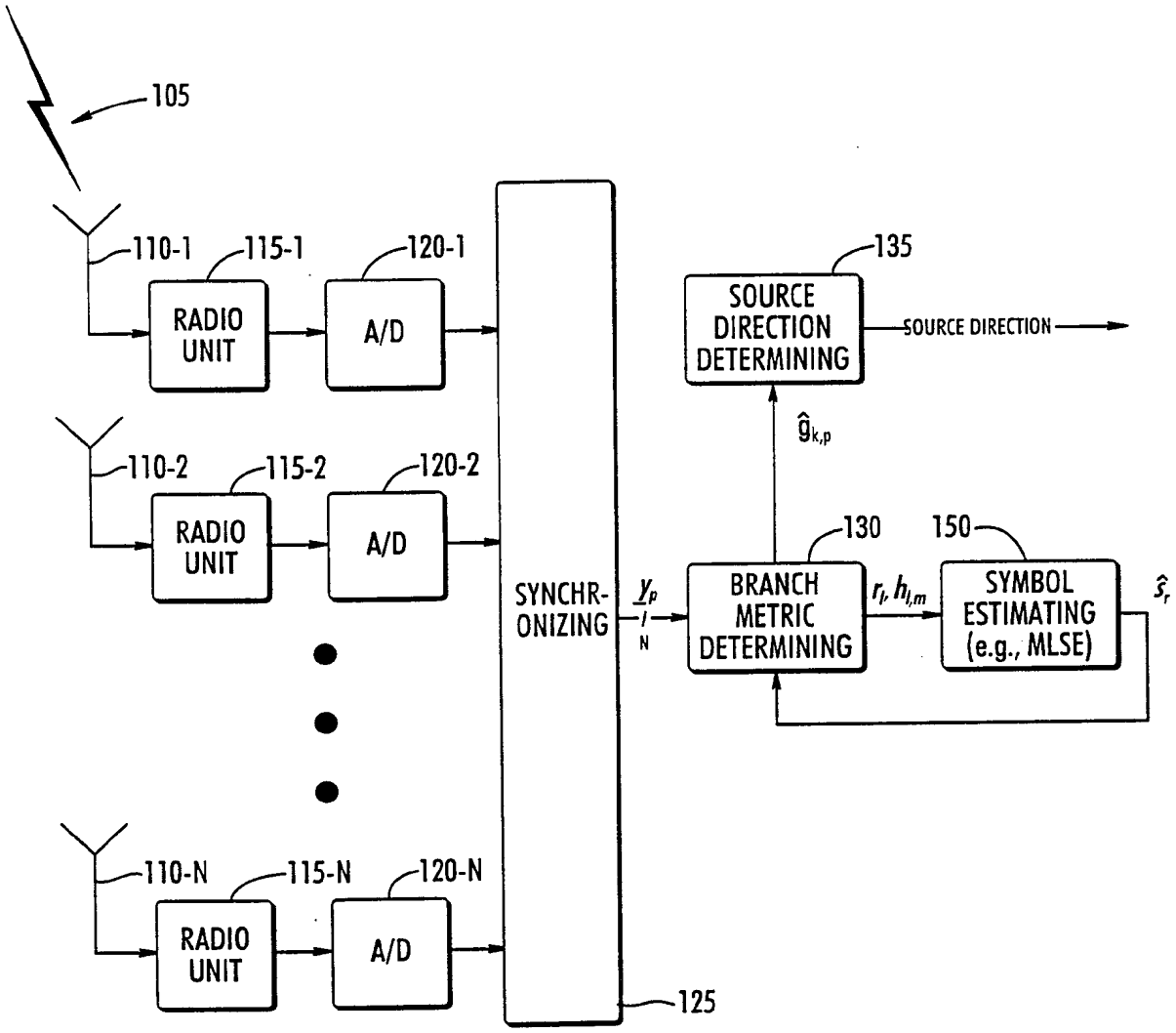
105
110-1
115-1
120-1
RADIO UNIT
A/D
110-2
115-2
120-2
RADIO UNIT
A/D
110-N
115-N
120-N
RADIO UNIT
A/D
SYNCHR-ONIZING
125
135
SOURCE DIRECTION DETERMINING
SOURCE DIRECTION
$\hat{g}_{k,p}$
130
150
BRANCH METRIC DETERMINING
$r_l, h_{l,m}$
SYMBOL ESTIMATING (e.g., MLSE)
$\hat{s}_r$
y_p
1
N

FIG. 1

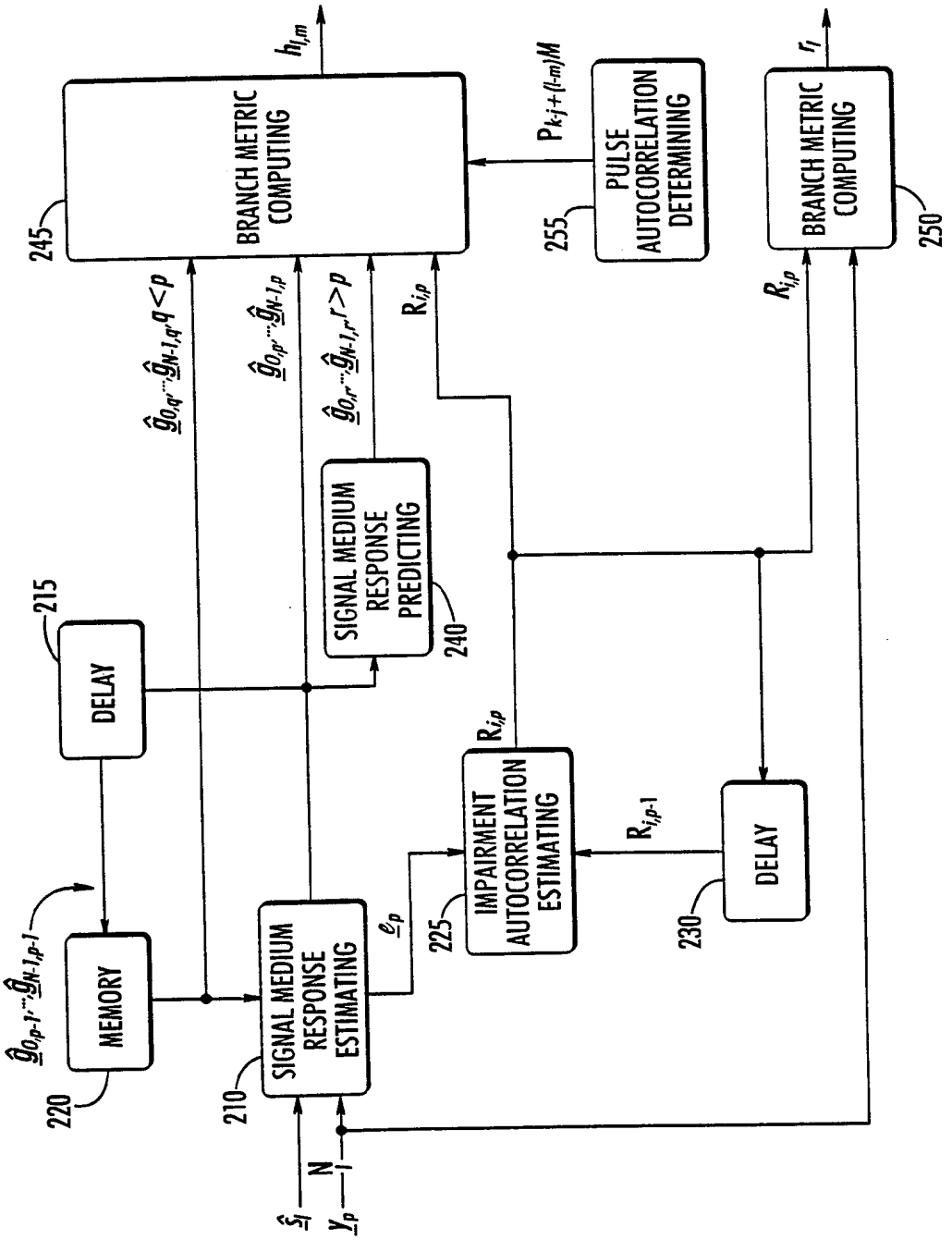
BRANCH METRIC COMPUTING
245
$h_{l,m}$
PULSE AUTOCORRELATION DETERMINING
255
$P_{k,j+(l-m)M}$
BRANCH METRIC COMPUTING
250
r_l
$\hat{g}_{0,q}\cdots\hat{g}_{N-1,q}\ q<p$
$\hat{g}_{0,p}\cdots\hat{g}_{N-1,p}$
$\hat{g}_{0,r}\cdots\hat{g}_{N-1,r}\ r>p$
$R_{i,p}$
$R_{i,p}$
SIGNAL MEDIUM RESPONSE PREDICTING
240
DELAY
215
$R_{i,p}$
IMPAIRMENT AUTOCORRELATION ESTIMATING
225
$R_{i,p-1}$
DELAY
230
e_p
SIGNAL MEDIUM RESPONSE ESTIMATING
210
MEMORY
220
$\hat{g}_{0,p-1}\cdots\hat{g}_{N-1,p-1}$
$\hat{s}_l$
N
y_p
I

FIG. 2

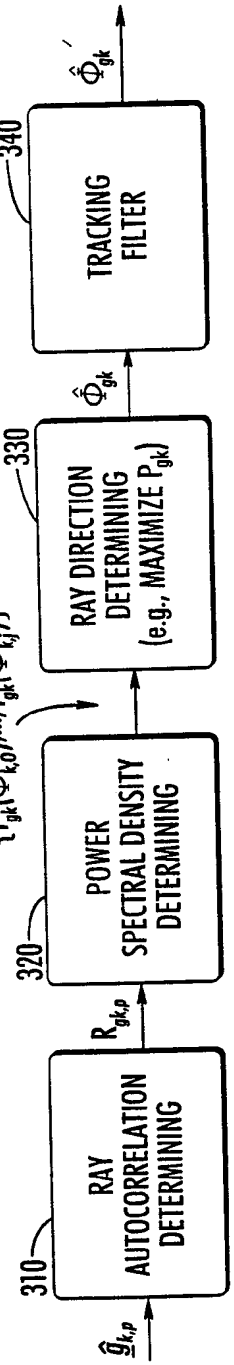
$\hat{g}_{k,p}$
310
RAY AUTOCORRELATION DETERMINING
$R_{gk,p}$
320
POWER SPECTRAL DENSITY DETERMINING
$\{P_{gk}(\Phi_{k,0}),\ldots,P_{gk}(\Phi_{k,j})\}$
330
RAY DIRECTION DETERMINING (e.g., MAXIMIZE P_{gk})
$\hat{\Phi}_{gk}$
340
TRACKING FILTER
$\hat{\Phi}'_{gk}$

FIG. 3

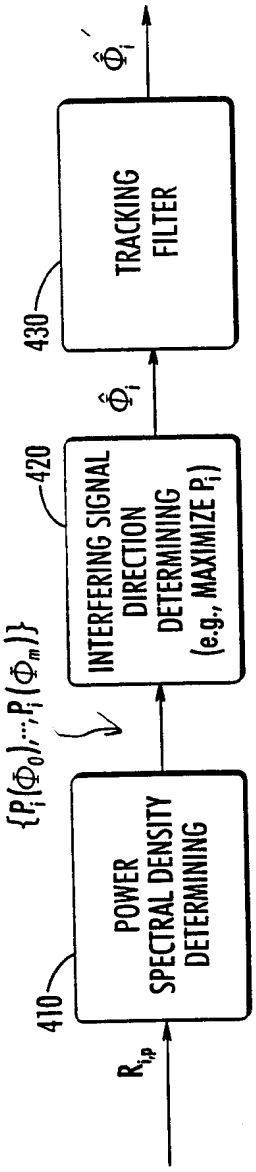
$R_{i,p}$
410
POWER SPECTRAL DENSITY DETERMINING
$\{P_i(\Phi_0),\ldots,P_i(\Phi_m)\}$
420
INTERFERING SIGNAL DIRECTION DETERMINING (e.g., MAXIMIZE P_i)
$\hat{\Phi}_i$
430
TRACKING FILTER
$\hat{\Phi}'_i$

FIG. 4

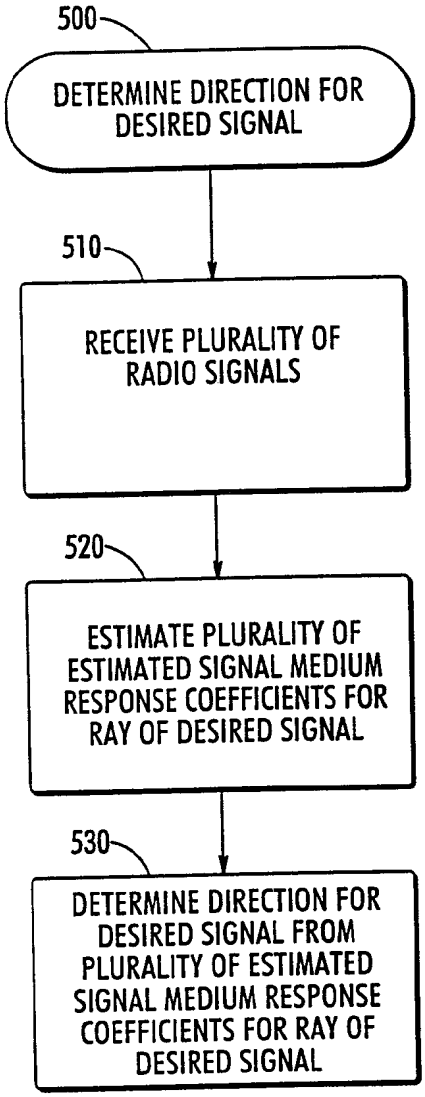
500
DETERMINE DIRECTION FOR DESIRED SIGNAL
510
RECEIVE PLURALITY OF RADIO SIGNALS
520
ESTIMATE PLURALITY OF ESTIMATED SIGNAL MEDIUM RESPONSE COEFFICIENTS FOR RAY OF DESIRED SIGNAL
530
DETERMINE DIRECTION FOR DESIRED SIGNAL FROM PLURALITY OF ESTIMATED SIGNAL MEDIUM RESPONSE COEFFICIENTS FOR RAY OF DESIRED SIGNAL

FIG. 5

INTERNATIONAL SEARCH REPORT

Interr al Application No
PCT/US 98/27104

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B7/005

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO 98 36596 A (NOKIA TELECOMMUNICATIONS OY ;KATZ MARCOS (FI)) 20 August 1998	1,20
A	see abstract see page 3, line 7 - page 9, line 26 see page 17, line 17 - page 23, line 32 see figure 5	2-19, 21-38

A	WO 97 45968 A (ERICSSON TELEFON AB L M) 4 December 1997 see abstract see page 3, line 20 - page 4, line 11 see page 13, line 15 - page 16, line 29 see figures 4-6	1-38

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 March 1999	07/04/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Cochonneau, O

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Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/US 98/27104

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97 02666 A (NOKIA TELECOMMUNICATIONS OY ;KESKITALO ILKKA (FI); KIISKI MATTI (F) 23 January 1997 see abstract see page 4, line 22 - page 6, line 6 see figures 2,4 ---	1-38
A	WO 96 04738 A (ERICSSON GE MOBILE INC) 15 February 1996 see abstract see page 3, line 3 - page 4, line 33 see figures 2,7,8 ---	1-38
A	WO 96 31010 A (SIEMENS AG ;HAARDT MARTIN (DE)) 3 October 1996 see abstract see page 2, line 30 - page 6, line 10 -----	1-38

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter .al Application No
PCT/US 98/27104

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